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A New Galactic 6 cm Formaldehyde Maser

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ABSTRACT

We report the detection of a new H₂CO maser in the massive star forming region G23.71–0.20 (IRAS 18324–0820), i.e., the fifth region in the Galaxy where H₂CO maser emission has been found. The new H₂CO maser is located toward a compact H II region, and is coincident in velocity and position with 6.7 GHz methanol masers and with an IR source as revealed by Spitzer/IRAC GLIMPSE data. The coincidence with an IR source and 6.7 GHz methanol masers suggests that the maser is in close proximity to an embedded massive protostar. Thus, the detection of H₂CO maser emission toward G23.71–0.20 supports the trend that H₂CO 6 cm masers trace molecular material very near young massive stellar objects.

Subject headings: HII regions — ISM: molecules — masers — radio lines: ISM — stars: formation — ISM: individual (G23.71–0.20)

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1. Introduction

The 6 cm transition of formaldehyde (H_2CO , $J_{K_a K_c} = 1_{11} - 1_{10}$) was among the first molecular lines detected in the interstellar medium. This transition is ubiquitously observed in absorption against Galactic continuum sources (e.g., Araya et al. 2002) as well as against the 2.7 K Cosmic Microwave Background (e.g., Palmer et al. 1969). In contrast, only a handful of H_2CO 6 cm emitters have been detected: H_2CO megamaser emission has been confirmed toward three galaxies (Araya, Baan & Hofner 2004a), and in our Galaxy H_2CO emission has been detected toward 5 sources: (quasi) thermal emission toward the Orion BN/KL region, and maser emission toward NGC 7538 IRS1, Sgr B2, G29.96–0.02, and recently IRAS 18566+0408 (Araya et al. 2005).

All Galactic emitters are found in close proximity to signposts of young massive stars, indicating that the physical conditions necessary for H_2CO 6 cm emission occur in early phases of massive star formation. In addition, the low detection rate of H_2CO masers may be a consequence of specific and short lived physical conditions in massive star forming regions, thus H_2CO masers could become a valuable astrophysical probe if the excitation mechanism of the maser was known. However, the physical mechanism for H_2CO 6 cm maser emission is still not understood. Currently, the only quantitative model proposed to explain H_2CO 6 cm masers is that of Boland & de Jong (1981), where the level inversion is caused by the radio continuum from a background compact HII region. Unfortunately, this model cannot explain most of the known H_2CO 6 cm masers (e.g., Hoffman et al. 2003). The lack of progress in the understanding of the H_2CO 6 cm maser mechanism is in part due to the small sample of known H_2CO maser regions. A larger sample of H_2CO maser regions would not only serve to further test the Boland & de Jong (1981) model, but also to investigate the dependence of H_2CO masers on a larger variety of physical environments, e.g., to check whether H_2CO masers are preferentially associated with shocked gas or with more quiescent molecular material that could be radiatively excited.

With the goal of increasing the number of known H_2CO 6 cm maser regions, we conducted in 2002 and 2003 a survey for H_2CO 6 cm emission with the Arecibo telescope (Araya et al. 2004b). In the survey we observed massive star forming regions characterized by high molecular densities and low radio-continuum at 6 cm, and detected H_2CO 6 cm maser emission toward IRAS 18566+0408 (Araya et al. 2005). Motivated by our first Arecibo survey, we recently completed a second survey with the GBT and VLA¹. The main result of our

¹The 100 m Green Bank Telescope (GBT) and the Very Large Array (VLA) are operated by the National Radio Astronomy Observatory (NRAO), a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

second survey, which is reported in this letter, is the discovery of a new H_2CO 6 cm maser toward the massive star forming region G23.71–0.20.

2. Observations and Data Reduction

On 2005 January 10, we conducted an H_2CO 6 cm maser survey toward 10 massive star forming regions with the VLA in the A configuration. The sources were selected based on single dish H_2CO spectra that had been obtained by our group with the Arecibo and GBT telescopes (Watson et al. 2003, Sewilo et al. 2004a), and that were consistent with H_2CO absorption blended with emission. We detected radio continuum and H_2CO 6 cm absorption toward several regions, and a new H_2CO 6 cm emitter toward G23.71–0.20 (IRAS 18324–0820). This latter detection is the topic of this letter. The results for the non-emitting regions will be presented in a future paper (Araya et al. *in prep.*). Further observations of the G23.71–0.20 region were conducted on 2005 April 24, with the VLA in the B configuration. These observations were intended to confirm the detection. In Table 1, we list details of the spectral line observations conducted with the VLA in the A and B configurations. The data were calibrated and imaged in AIPS following standard spectral-line reduction procedures. Only external calibration (i.e., no self-calibration) was used to obtain the complex gain corrections for data calibration. We did not detect radio continuum in individual channels, hence continuum subtraction was not necessary. No bandpass calibration was necessary due to the narrow bandwidth.

3. Results and Discussion

3.1. A New H_2CO 6 cm Maser in the Galaxy

Using the VLA in the A configuration we detected H_2CO 6 cm emission toward G23.71–0.20. The emission was detected in two channels (i.e., width 0.76 km s^{-1}) with an rms noise of $4.5 \text{ mJy beam}^{-1}$ in a natural weighted map. The peak intensity is $I_\nu = 60 \text{ mJy beam}^{-1}$ at the velocity $V_{\text{max}} = 79.2 \text{ km s}^{-1}$. The maximum intensity of the H_2CO emission is located at $\alpha(\text{J2000}) = 18^{\text{h}}35^{\text{m}}12^{\text{s}}.37$, $\delta(\text{J2000}) = -08^\circ17'39''.3$. The emission feature is unresolved ($\theta_{\text{source}} < 0''.4$), which implies a lower limit on the brightness temperature of $\sim 30000 \text{ K}$, i.e., the emission is due to a maser mechanism. The intensity of this new maser is similar to the 70 mJy/beam of the maser in G29.96–0.02 (Pratap, Menten, & Snyder, 1994). On the other hand, the maser in G23.71–0.20 is narrower in comparison with other H_2CO masers (e.g., the FWHM of the maser in IRAS 18566+0408 is 1.6 km s^{-1} , Araya et al. 2005, whereas the FWHM of the new maser is smaller than 0.8 km s^{-1}).

The VLA-B observations confirmed the existence of the H₂CO 6 cm maser in G23.71–0.20. As in the VLA-A observations, the maser is detected in two channels (0.76 km s^{−1}) with a signal to noise ratio greater than 4 (rms ∼ 6.0 mJy beam^{−1}). We measured a peak velocity and intensity values of $V_{max} = 79.2 \text{ km s}^{-1}$ and $I_\nu = 44 \text{ mJy beam}^{-1}$ ($T_B > 400 \text{ K}$), respectively. The H₂CO peak intensity measured with the VLA-B is less than the peak intensity measured with the VLA-A, however both values are consistent within 5σ . We combined the VLA-A and B *uv* data to produce the map and spectrum shown in Figure 1. The spectrum in Figure 1 shows that H₂CO emission may also be present in the two lower-velocity channels blueward of the peak channel.

3.2. An Overview of the G23.71–0.20 Massive Star Forming Region

G23.71–0.20 is a massive star forming region located in the Scutum constellation. Sewilo et al. (2004a) reported H110 α emission from the region at a LSR velocity of 76.5 km s^{−1}, hence, the H₂CO maser LSR velocity is coincident (within ∼2.7 km s^{−1}) with the H110 α line center. This velocity correspondence implies that the H₂CO maser is associated with the G23.71–0.20 massive star forming region. Based on the LSR velocity of the H110 α line, the two possible kinematic distances of G23.71–0.20 are 4.9 kpc and 11 kpc. Sewilo et al. (2004a) considered the far kinematic distance (i.e., $D_{LSR} \sim 11 \text{ kpc}$) as more likely.

Becker et al. (1994) (see also White, Becker, & Helfand 2005) detected 6 cm radio continuum from the region. In Figure 2 we show their VLA-C 6 cm continuum map². As the figure illustrates, the H₂CO maser is not coincident with the strong radio continuum emission, but rather lies in an area of more diffuse emission. Apart from the 6 cm detection by White et al. (2005), no other high-angular resolution detection of the radio continuum at frequencies above 2 GHz³ is available. Future high-angular resolution observations of the radio continuum of the region at several frequencies are required to test if the H₂CO maser in G23.71–0.20 can be explained by the Boland & de Jong (1981) model.

The radio continuum source in G23.71–0.20 is coincident with IRAS 18324–0820, which has the characteristic far-infrared color of ultra-compact H II regions (Sewilo et al. 2004a). Assuming a distance of 11 kpc, isotropic emission, and following the formulation of Casoli et al. (1986), we estimate a bolometric luminosity of $\sim 2.4 \times 10^5 L_\odot$, which corresponds to the luminosity of an ∼O6 ZAMS star (Panagia 1973).

²Multi-Array Galactic Plane Imaging Survey, <http://third.ucllnl.org/gps/>.

³The region was detected in VLA L-band (20 cm) surveys: NVSS (Condon, et al. 1998), and the Multi-Array Galactic Plane Imaging Survey (White et al. 2005).

High angular resolution studies of molecular line transitions toward G23.71–0.20 are as scarce as the radio continuum observations. The only available interferometric molecular data of the region are from Walsh et al. (1998). They detected seven CH₃OH 6.7 GHz maser spots in the region. In Figure 2, we show the positions of these masers. The CH₃OH 6.7 GHz masers are all coincident with the H₂CO 6 cm maser within $\sim 1''$, which is the absolute positional accuracy of the CH₃OH masers (Walsh et al. 1998). The masers are spread over a velocity range from 74.9 to 81.4 km s^{−1}, which encompasses the velocity of the H₂CO maser (79.2 km s^{−1}).

G23.71–0.20 has been detected in several single dish surveys for CH₃OH masers: Blaszkiewicz & Kus (2004) (12.2 GHz CH₃OH masers); Schutte et al. (1993), Slysh et al. (1999), Szymczak, Hrynek, & Kus (2000) (6.7 GHz CH₃OH masers). In all cases, the CH₃OH masers show similar velocities to that of the H₂CO maser. G23.71–0.20 was also observed in CS J=2–1 by Bronfman, Nyman, & May (1996). They detected CS J=2–1 emission at a velocity of 68.3 km s^{−1}, which is approximately 10 km s^{−1} lower than that of the H₂CO maser. Finally, Han et al. (1998) conducted a survey of 22 GHz H₂O masers at the Purple Mountain Observatory, and report detection of a 35.6 Jy H₂O maser at a LSR velocity of −40.3 km s^{−1}. This radial velocity is very different from the velocity of the H₂CO maser (79.2 km s^{−1}), thus the association of this H₂O maser with the H₂CO and CH₃OH masers is unclear.

We searched the MSX and Spitzer/IRAC GLIMPSE images for infrared (IR) emission in the vicinity of the H₂CO maser position. The 21.3 μ m emission seen in the MSX E band (angular resolution 18'') partly traces the two main 6 cm continuum emission regions to the SE and SW of the maser position, but also shows extended emission near the maser position. The Spitzer/IRAC GLIMPSE data show a compact IR source located within 0'.3 of the H₂CO maser position. This source is detected in all four IRAC bands. In Figure 3 we show a color-coded image of the Spitzer data (blue is the average of the 3.6 and 4.5 μ m data, green is 5.8 μ m, and red is 8.0 μ m), and we mark the position of the H₂CO maser with a cross. While the [3.6]–[4.5] color of 2.1 is indicative of a deeply embedded object, the [5.8]–[8.0] color of 0.1 is peculiar in combination with the first color (see Indebetouw et al. 2006). The [5.8]–[8.0] color could be caused by unresolved source multiplicity and/or the presence of PAH emission features. In addition, strong and broad ~ 10 μ m silicate absorption could be affecting the 8.0 μ m band. High angular resolution infrared observations are underway to further study this IR source.

3.3. Implication for the Nature of H₂CO 6 cm Masers

The inversion mechanism of H₂CO 6 cm masers is unclear (e.g., Mehringer, Goss, & Palmer 1994). Besides the model by Boland & de Jong (1981) which is based on radiative excitation by radio continuum, Hoffman et al. (2003) suggested that H₂CO 6 cm masers could be collisionally pumped. The new detection of an H₂CO 6 cm maser in G23.71–0.20 and the coincidence of the maser with a Spitzer compact source (Figure 3) suggests another possibility: H₂CO 6 cm masers could be radiatively pumped by IR photons in massive star forming regions. A connection between FIR radiation and H₂CO 6 cm masers has been noticed before in megamaser galaxies, e.g., the data by Araya et al. (2004a) suggest a correlation between the luminosity of H₂CO megamaser lines and FIR luminosity (see also Baan, Haschick, & Uglesich 1993). In addition, Litvak (1970) pointed out that absorption of infrared radiation in conjunction with large H₂CO optical depths and H₂CO density comparable to that of OH maser regions, may result in H₂CO maser emission. Quantitative models have been developed to explain OH masers via FIR radiative excitation (e.g., Henkel, Güsten, & Baan 1987; Cesaroni & Walmsley 1991), however, to date there exist no equivalent models exploring pumping of the observed H₂CO 6 cm masers via IR photons.

The idea of FIR pumping of H₂CO masers is compelling; however a quantitative test of this hypothesis is not practical since (as mentioned in section 3.2) the available data toward the H₂CO maser in G23.71–0.20 do not provide sufficient constraints to carry out an analysis of the inversion mechanism. Specifically, the FIR fluxes measured by IRAS toward G23.71–0.20 are likely to trace the extended IR region to the SW of the maser position (see Figure 3) and not the FIR properties of the compact Spitzer source.

In the case of G23.71–0.20, the other proposed pumping mechanisms cannot be currently tested either. The radio continuum at the position of the maser is blended with emission from two nearby continuum regions, thus neither the gain of the maser or the emission measure of the ionized gas at the maser position can be determined. In addition, the thermal molecular data (e.g., CS) are insufficient to establish whether the H₂CO maser is associated with a molecular clump or outflow, and we also lack high quality information about shock tracers like H₂O masers that may be associated with H₂CO masers (e.g., Araya et al. 2005).

On the other hand, the detection of maser emission in G23.71–0.20 supports the trend that H₂CO masers reside very near to massive young stellar objects (YSOs), i.e., closer than a few thousand AU. For example, the maser in G29.96–0.02 is coincident with a hot molecular core (Pratap et al. 1994) that probably contains a massive circumstellar disk (Olmi et al. 2003); the maser in IRAS 18566+0408 is coincident with a 2MASS and a bright Spitzer/GLIMPSE source (Araya et al. 2005, 2006 in prep.) and the central continuum

object has been classified as a massive disk candidate (Zhang 2005). Also, the maser in NGC 7538 IRS1 (which shows an H_2CO NE–SW velocity gradient, Hoffman et al. 2003) is located at the position of an hypercompact HII region candidate (Sewilo et al. 2004b) that harbors a possible circumstellar disk oriented in a NE–SW direction (De Buizer & Minier 2005). The close association of H_2CO masers with massive YSOs is in contrast to other molecular masers (e.g., 44 GHz CH_3OH masers, Kurtz, Hofner, & Vargas-Álvarez 2004) that can be found at larger distances from massive YSOs and are probably related to the interaction of jets and outflows with the surrounding material of the molecular cloud. If the H_2CO masers are associated with shocked gas, then they might trace the regions where accretion from a mass reservoir to a massive circumstellar disk occurs.

4. Summary

Using the VLA in the A configuration we detected H_2CO emission from the massive star forming region G23.71–0.20. Based on the brightness temperature limit of the detection ($T_b > 30000\text{ K}$), the line must be due to a maser mechanism: i.e., this source is the fifth region in the Galaxy where H_2CO 6 cm maser emission has been detected. The FWHM of the line is $< 0.8\text{ km s}^{-1}$, i.e., narrower than other H_2CO masers detected with the VLA. The maser was independently confirmed by VLA-B observations of the region, that were conducted approximately 3 months after the initial detection. The LSR velocity and position of the maser closely correspond to those of CH_3OH 6.7 GHz masers detected by Walsh et al. (1998) with the Australia Telescope Compact Array. We found a compact Spitzer/IRAC IR source, possibly a deeply embedded young stellar object, coincident with the H_2CO maser. The detection of H_2CO maser emission in G23.71–0.20 supports the trend that H_2CO 6 cm masers are located very near massive YSOs.

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Table 1. VLA Observations

Parameter	VLA-A	VLA-B
Date	2005 Jan. 10	2005 Apr. 24
RA ^a	18 ^h 35 ^m 12 ^s .54	18 ^h 35 ^m 12 ^s .54
Dec ^a	−08°17′46″.5	−08°17′46″.5
ν_o (GHz) ^b	4829.6569	4829.6569
V_{LSR} (km s ^{−1}) ^c	80.0	80.0
IF Mode	2IF (AD)	2IF (AD)
BW (MHz) ^d	1.56	1.56
(km s ^{−1})	97.0	97.0
$\Delta\nu^e$ (kHz)	6.104	6.104
(km s ^{−1})	0.38	0.38
Synth. Beam	0′.63×0′.41	3′.85×1′.44
Position Angle	1°	49°
Flux Density Calib.	3C 286	3C 48
Assumed S_ν	7.52	5.47
Phase Calib.	J1832−105	J1832−105
Measured S_ν	1.3	1.2
rms (mJy/beam) ^f	4.5	6.0

^aPhase tracking center (J2000) of the G23.71−0.20 observations.

^bRest frequency of the H₂CO $J_{K_a K_c} = 1_{10} - 1_{11}$ transition.

^cCentral bandpass velocity.

^dBandwidth per IF.

^eFinal channel width.

^fFinal rms in a channel map.

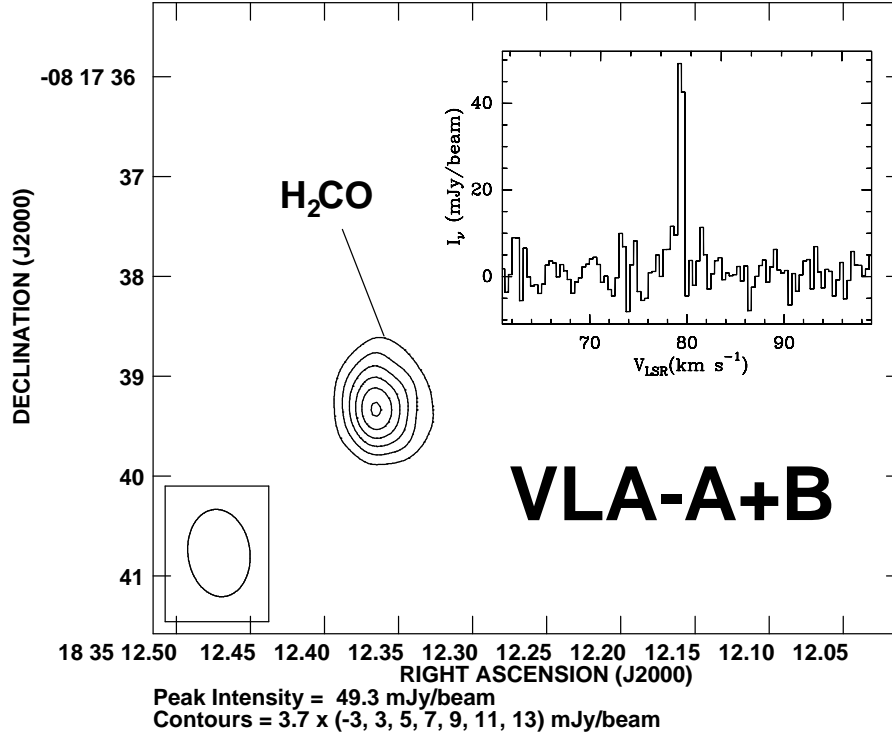


Fig. 1.— H₂CO 6 cm maser emission toward G23.71–0.20. We show the peak channel image (contours) and the H₂CO spectrum of the VLA-A+B combined data. The rms of the image is 3.7 mJy beam^{–1}, and θ_{syn} is 0''.88×0''.62, P.A. = 7°.

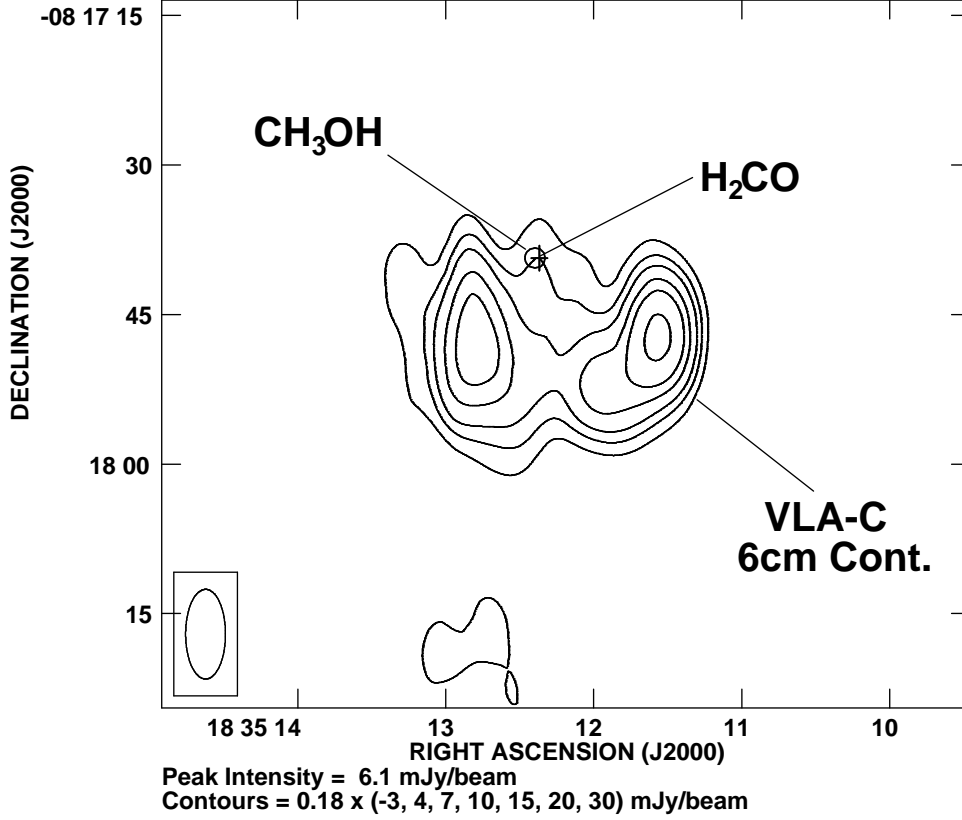


Fig. 2.— 6 cm VLA-C map from the Multi-Array Galactic Plane Imaging Survey (<http://third.ucllnl.org/gps/>, White et al. 2005). The rms of the image is $0.18 \text{ mJy beam}^{-1}$, the peak intensity is $6.1 \text{ mJy beam}^{-1}$, and the synthesized beam is $\sim 9'' \times 4''$, P.A. $\sim 0^\circ$. We also show the position of the H₂CO maser with a plus symbol (the size of the symbol is four times the size of the VLA-A synthesized beam), and the location of seven 6.7 GHz CH₃OH masers reported by Walsh et al. (1998) with a circle (all of them are located within $0''.2$ from each other, and the size of the circle is approximately twice the absolute position accuracy of the CH₃OH masers).

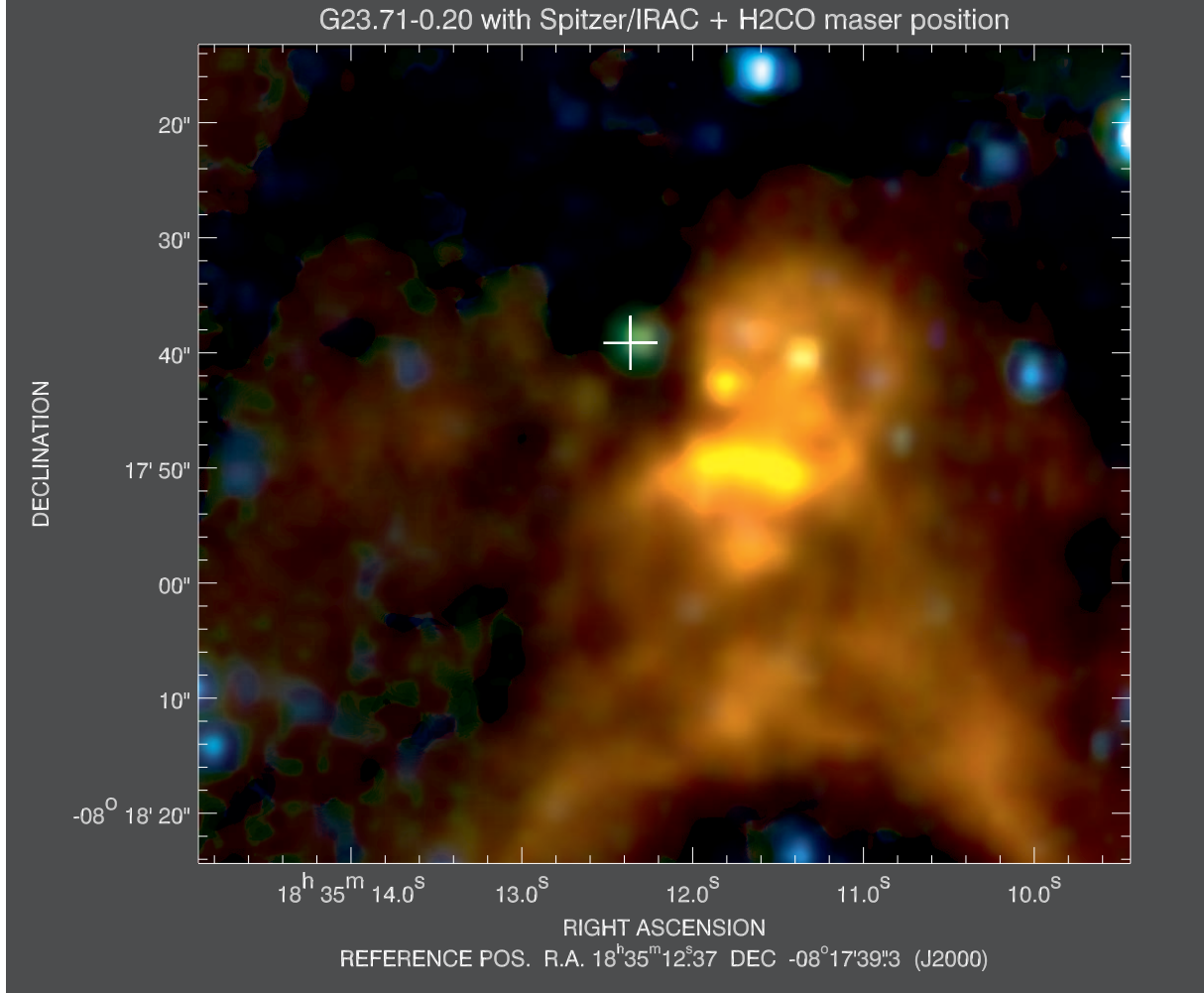


Fig. 3.— Spitzer/IRAC GLIMPSE color composite of the G23.71–0.20 region. Blue is the average of the 3.6 and 4.5 μm data, green is 5.8 μm , and red is 8.0 μm . The cross marks the position of the H₂CO maser. Note the detection of a compact IR source at the maser position.